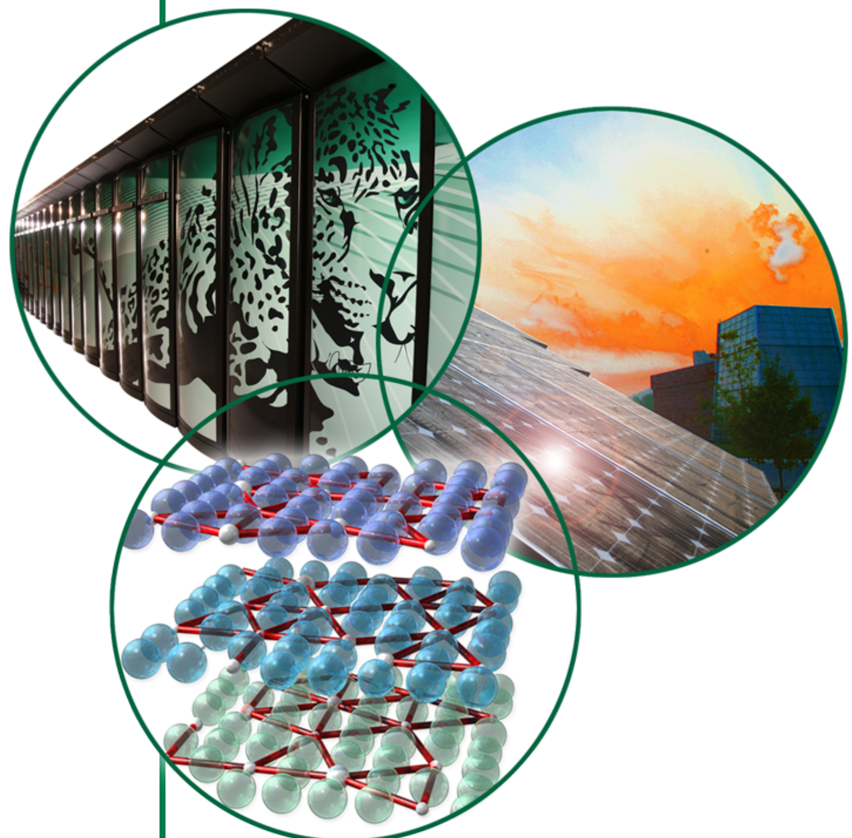
SILENE Benchmark Experiment for Criticality Accident Alarm Systems



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Outline

- Objective and requirements of benchmark
- Institutions involved
- Brief introduction to SILENE
  - Images taken from previous presentations give by Valduc staff
- Background
  - Equipment and expertise available at Valduc
  - Summary of FY 2010 activities leading up to actual experiments
- Details of benchmark experiments
- Future (FY 2011) work

Objective and requirements

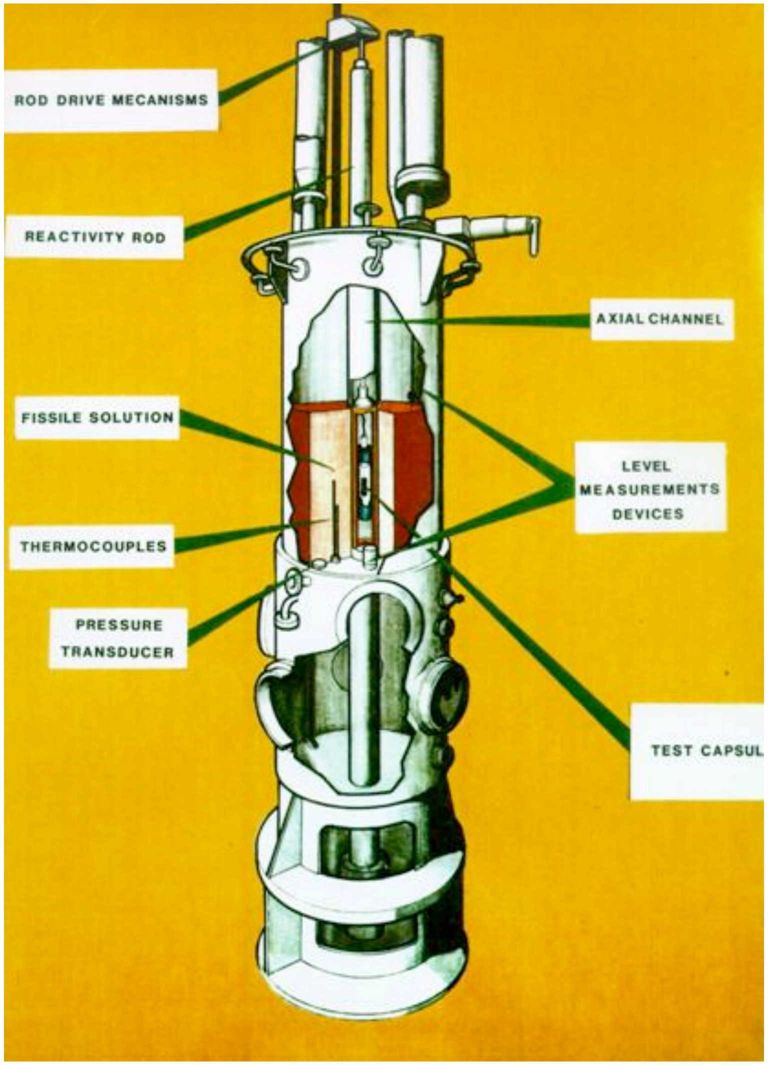
- Objective
  - To generate benchmark-quality data and associated information for validating computer codes and nuclear data used for CAAS analyses
- Requirements
  - Initial source must be representative of a criticality accident (there currently are no ICSBEP shielding benchmarks with a pulsed critical source)
  - Shielding and structural materials used must be representative of those used in facilities that require CAAS
  - Radiation detector responses must be representative of CAAS detector responses and measure neutrons and photons
  - Radiation characteristics being measured must be representative of those measured by actual CAAS (scattering and secondary particle generation)
  - All aspects of the experiments must be characterized, performed, and documented to a level sufficient for publication by the ICSBEP

Institutions involved in SILENE CAAS benchmarks

- Oak Ridge National Laboratory – lead laboratory
  - Experiment design
  - Computational benchmark evaluation
  - Experiment and benchmark documentation
- CEA Valduc
  - Irradiation facility
  - Experimental measurements
  - Experiment and benchmark documentation
- CEA Saclay
  - Shielding materials and associated stands and equipment
- Lawrence Livermore National Laboratory
  - Rocky Flats CAAS
- Babcock International Group
  - CIDAS CAAS
- Y-12 National Security Complex
  - BoroBond shielding materials
- Los Alamos National Laboratory
  - External review of experiment design

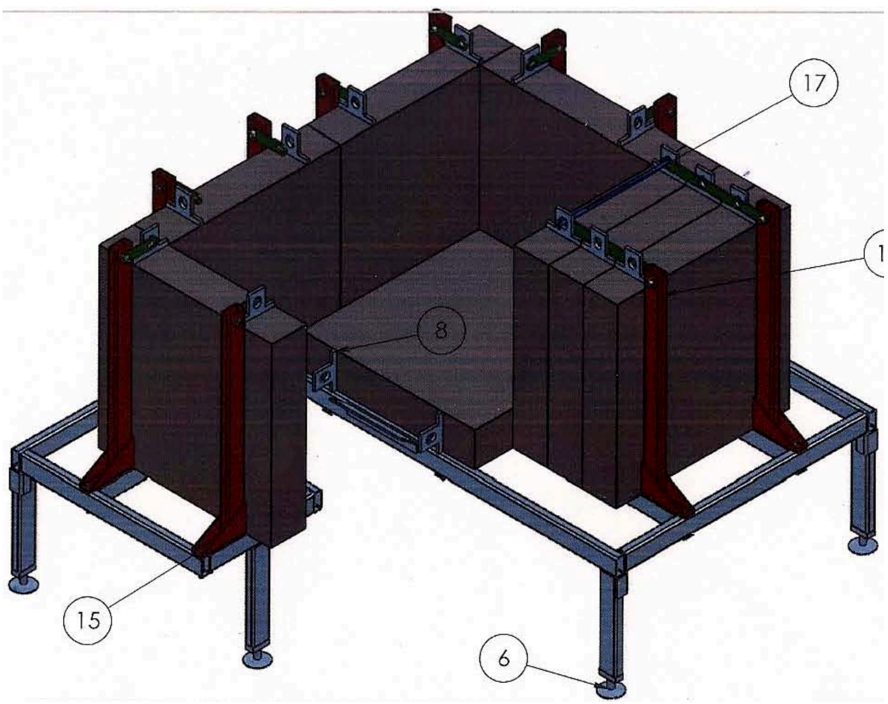
Introduction to SILENE

- Annular core
  - Internal cavity diameter 7 cm
  - Outer fuel diameter 36 cm
  - Typical critical height 35 – 45 cm
- Uranyl Nitrate fuel Solution
  - 93% ^{235}U
  - 71 g of uranium per L
- Power level ranges from 10 mW to 1000 MW
- Three operating modes
  - Single pulse
  - Free evolution
  - Steady State



Background: shielding materials

- Shield materials, collimators, and stands
  - 17 concrete slabs (1m x 1m x 20cm)
  - 3 core shields (lead, iron, cadmium lined polyethylene)
  - 5 BoroBond slabs (1m x 1m x , 2 1-inch, 3 2-inch)
  - MIRTE materials not available



Background: neutron and photon detectors

- Neutron activation foils available: Au, In, Fe, Ni, Co, Ti, Al, Mg
  - Valduc dosimetrists have found that neutron activation was difficult to measure, but not impossible, behind more than 20 cm of concrete for some threshold reactions (Ti, Al, and Mg)
  - Aluminum and Magnesium create the same short-lived products, which can be a problem during activation measurements
- Valduc provided Al_2O_3 TLDs and ORNL provided ^6LiF and ^7LiF TLDs
- Valduc also provided 2 NE213 liquid scintillation detectors to measure the neutron and photon spectra

Background: CAAS detectors

- Rocky Flats CAAS
  - LLNL will discuss in more detail later in this technical seminar
  - Neutron absorption in ^{6}LiF disc
  - Neutron detection via detection of triton & alpha particle by a Si solid state detector with pulse height discrimination
  - Alarms at 500 n/cm^{2}s
- CIDAS CAAS
  - Photon detection via Geiger Muller detector
  - Alarms set points
    - 280 nGy in less than 1 sec
    - 1.0 mGy/hr for greater than 1 sec

Summary of FY2010 accomplishments

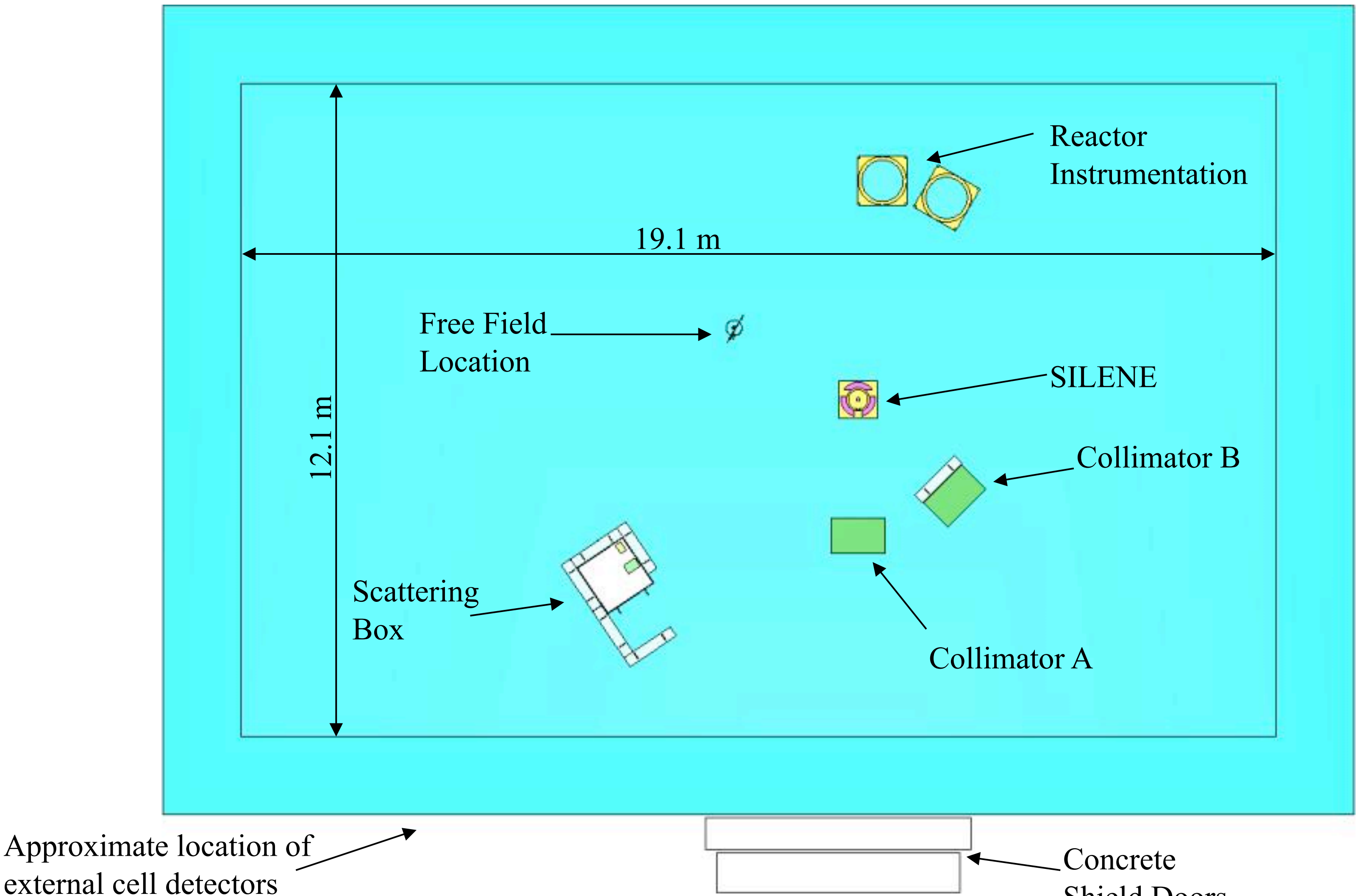
- Designed and organized an international multi-laboratory shielding benchmark experiment
- First experiment sponsored by the NCSP to be designed and conducted via the C_EdT Process (http://ncsp.llnl.gov/IERMain.html)
  - CED-0 justification of integral experiment need, approved early 2010
  - CED-1 integral experiment conceptual design, approved July 19, 2010
  - CED-2 integral experiment final design, approved September 27, 2010
  - CED-3 approval to conduct integral experiment, initiated September 27, 2010 and experiments conducted October 2010
  - CED-4 publication of data, future work

Actual experimental configurations

(Orange text deviates from the experimental plan)

- 3 single pulses: 1 unshielded, 1 with lead shield, 1 with polyethylene shield
- Surrounding SILENE for each pulse
  - 2 collimators and stands
  - Partially shielded detector location (scattering box)
  - Free-field detector location
  - Each location had a combination of neutron activation foils, TLDs, NE213 scintillator, and/or CAAS detector(s)
- Detectors were placed outside the SILENE reactor cell during each pulse

Plan view of SILENE reactor cell for pulse 1



Pulse 1 configuration

- SILENE bare (unshielded / no reflector)
- Collimator A
  - Unshielded
  - Full set of activation foils (Au, In, Fe, Co, Ni, Mg)
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
  - Rocky Flats CAAS
- Collimator B
  - 20 cm barite concrete shield
  - Full set of activation foils
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
  - Rocky Flats & CIDAS CAAS
- Scattering Box
  - 2 magnetite concrete shield blocks and 4 standard concrete shield blocks
  - Full set of activation foils
  - 3 partial sets of activation foils (Au, Co, Ni)
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
  - Rocky Flats & CIDAS CAAS
- Free field location
  - Full set of activation foils
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
- External cell location
  - 2 HBG and 2 DXT TLDs
  - Rocky Flats & CIDAS CAAS
  - 2 NE213 scintillators

Pulse 2 configuration

- SILENE with lead shield
- Collimator A
  - Unshielded
  - Full set of activation foils (Au, In, Fe, Co, Ni, Mg)
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
  - Rocky Flats CAAS
- Collimator B
  - 20 cm standard concrete shield
  - Full set of activation foils
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
  - Rocky Flats & CIDAS CAAS
- Scattering Box
  - 2 magnetite concrete shield blocks and 4 standard concrete shield blocks
  - Full set of activation foils
  - 3 partial sets of activation foils (Au, Co, Ni)
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
  - Rocky Flats & CIDAS CAAS
- Free field location
  - Full set of activation foils
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
- External cell location
  - 2 HBG and 2 DXT TLDs
  - Rocky Flats & CIDAS CAAS
  - 2 NE213 scintillators

Pulse 3 configuration

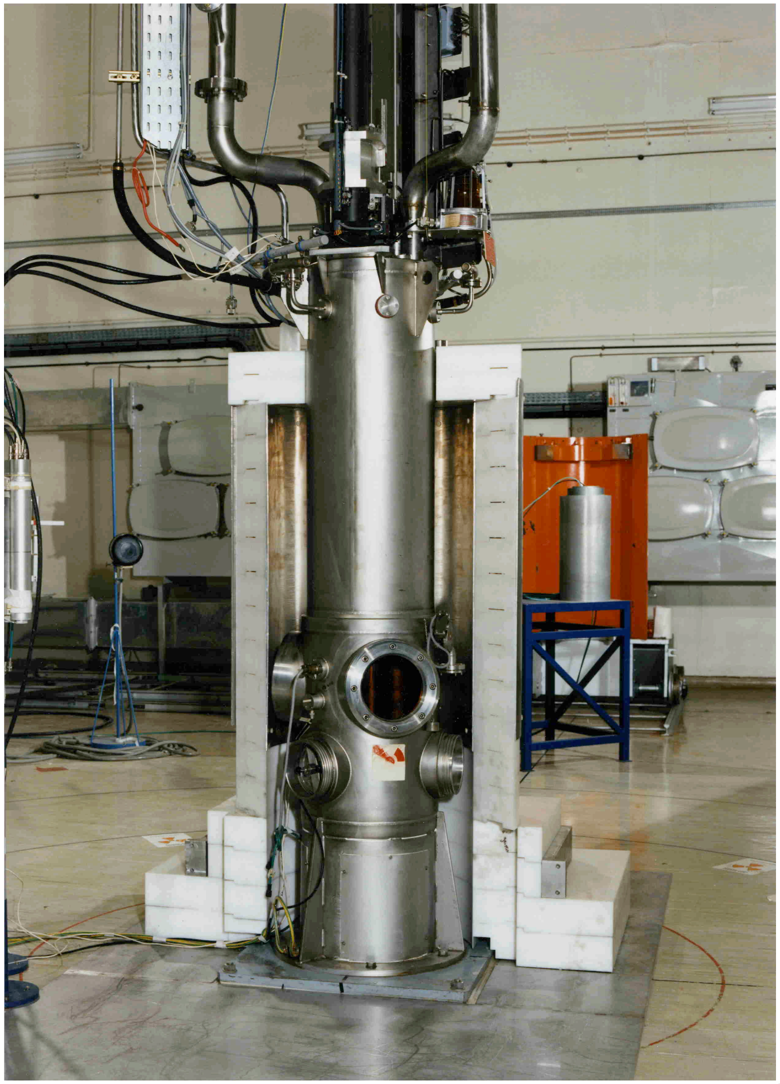
- SILENE with cadmium lined polyethylene shield
- Collimator A
  - Unshielded
  - Full set of activation foils (Au, In, Fe, Co, Ni, Mg)
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
  - Rocky Flats CAAS
- Collimator B
  - 3 inch BoroBond shield
  - Full set of activation foils
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
  - Rocky Flats & CIDAS CAAS
- Scattering Box
  - 2 magnetite concrete shield blocks and 4 standard concrete shield blocks
  - Full set of activation foils
  - 3 partial sets of activation foils (Au, Co, Ni)
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
  - Rocky Flats & CIDAS CAAS
- Free field location
  - Full set of activation foils
  - Valduc Al_2O_3 TLD & ORNL HBG and DXT TLDs
- External cell location
  - 2 HBG and 2 DXT TLDs
  - Rocky Flats & CIDAS CAAS
  - 2 NE213 scintillators

Pulse configurations

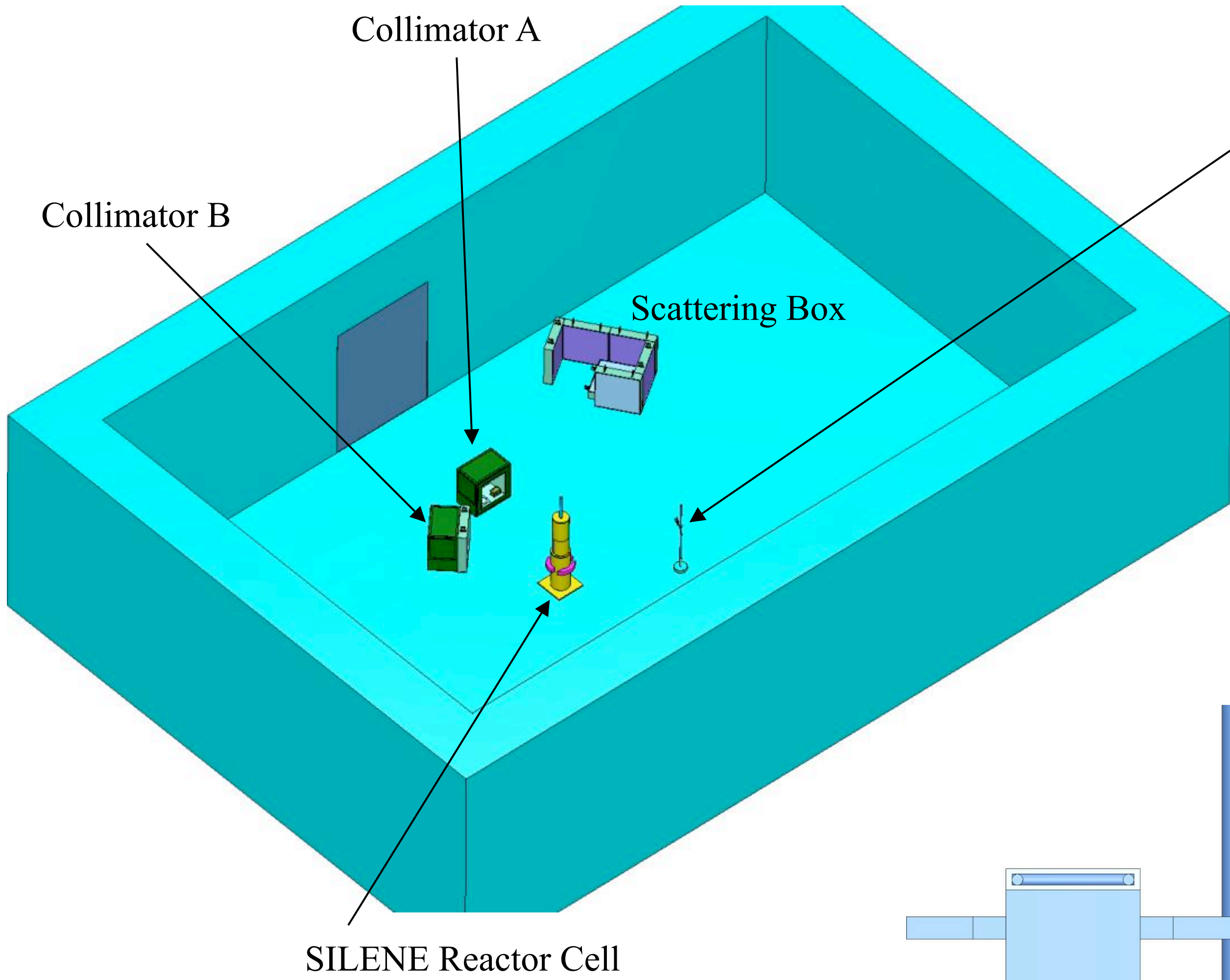
SILENE Shielding Materials / Reflectors			
Unshielded	Lead	Iron	Polyethylene (Cd liner)
Pulse 1	Pulse 2		Pulse 3

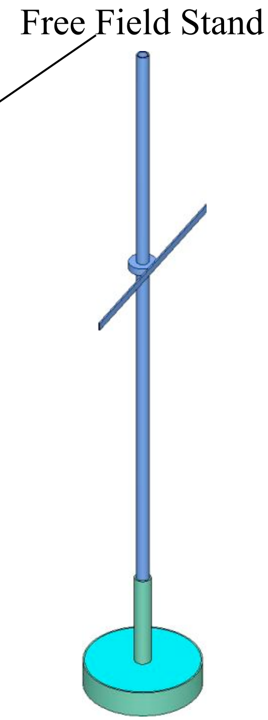
Locations and Detectors	Detector Shielding Materials					
	Concrete Walls	Unshielded	Standard Concrete	Magnetite Concrete	Barite Concrete	BoroBond
Collimator A: 1 Full set of activation foils Al_2O_3, HBG, DXT TLDs Rocky Flats CAAS		Pulse 1 Pulse 2 Pulse 3				
Collimator B: 1 Full set of activation foils Al_2O_3, HBG, DXT TLDs Rocky Flats & CIDAS CAAS			Pulse 2		Pulse 1	Pulse 3
Partially Shielded (Scattering Box): 1 Full set of activation foils 3 Partial sets of activation foils Al_2O_3, HBG, DXT TLDs Rocky Flats & CIDAS CAAS			Pulse 1 Pulse 2 Pulse 3	Pulse 1 Pulse 2 Pulse 3		
Free Field: 1 Full set of activation foils Al_2O_3, HBG, DXT TLDs		Pulse 1 Pulse 2 Pulse 3				
External to cell: 2 HBG & 2 DXT TLDs Rocky Flats & CIDAS CAAS 2 NE 213 liquid scintillators	Pulse 1 Pulse 2 Pulse 3					

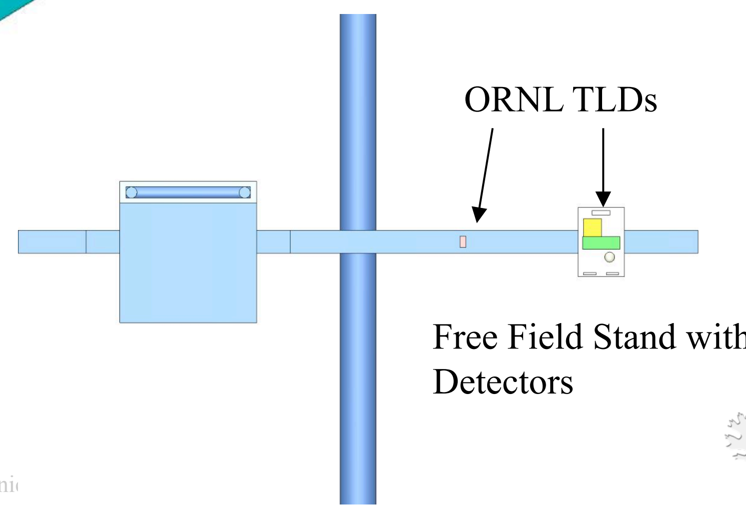
Photographs of SILENE cell



Images of SCALE models



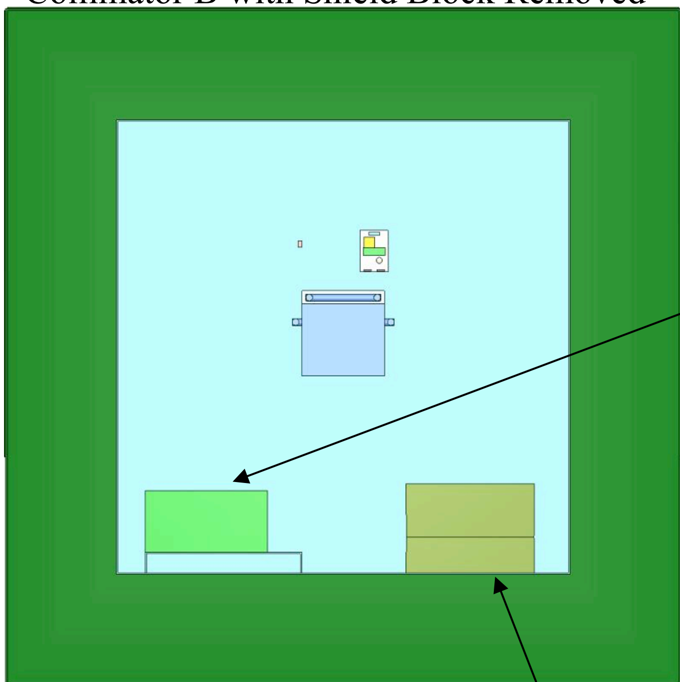


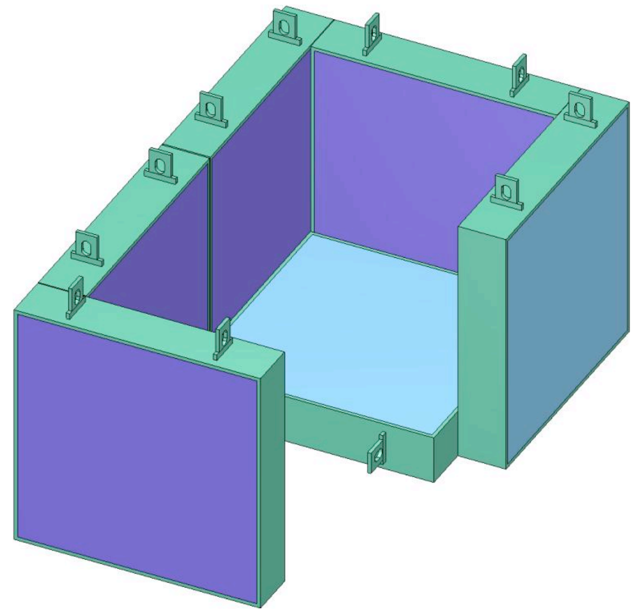


Free Field Stand with Detectors

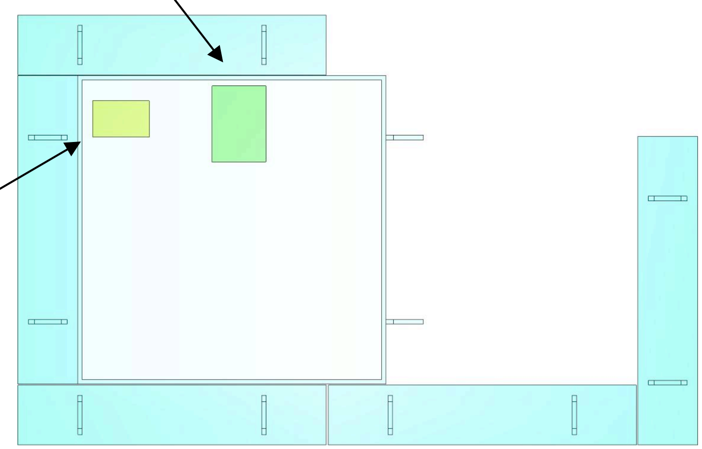
Images of SCALE models

Collimator B with Shield Block Removed



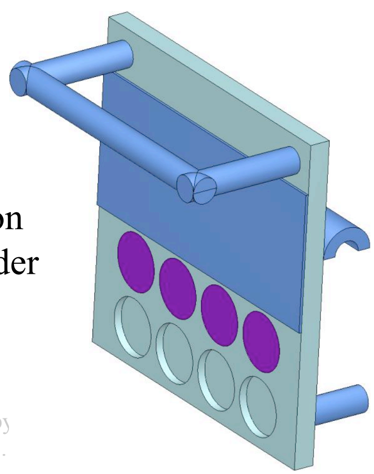


CIDAS
CAAS



Rocky Flats
CAAS

Neutron
Activation
Foil Holder



Comments on significant deviations from the experimental plan

- The partially shielded location or scattering box construction and placement suffered from problems with the reactor cell overhead crane
  - Different concrete, magnetite and standard concrete versus all standard concrete
  - Different location, 4.828 m along 123.926° versus 2.0 m along 135.0°
- The fourth experiment, free evolution, was not performed due to mechanical issues

Summary of individual pulses
(preliminary data currently available)

	Pulse 1	Pulse 2	Pulse 3
SILENE Shield	Bare	Lead	Polyethylene
Critical Height (cm)	37.333	31.322	34.637
Final Height (cm)	41.871	34.560	
Fission Chamber 1 (fissions)	1.83e17	2.15e17	
Fission Chamber 2 (fissions)	1.89e17	2.15e17	1.92e17
SNAC 50 (fissions)	1.73e17		

Preliminary neutron activation measurement data (kBq/g)

Pulse 1		
Position	**$^{115}In(n,g)^{116m}In$**	**$^{56}Fe(n,p)^{56}Mn$**
Collimator A	9100	2.3
Collimator B	3000	0.8
Scattering Box	2700	0.9
Free Field	8800	2.4
Pulse 2		
Position		**$^{56}Fe(n,p)^{56}Mn$**
Collimator A		2.2
Collimator B		1.0
Scattering Box		0.88
Free Field		2.1

- Experimental uncertainty less than 4%
- New computational results (as compared to the experiment plan) are forth coming, additional geometry and material data is being gathered by CEA Valduc and CEA Saclay

Conclusions based on preliminary neutron activation data measurements and experiment plan calculations

- Below is a comparison between measurement data and calculations performed during the experiment planning
- Collimator A and the free field location were selected because the actual experimental configurations at these locations are not significantly different from the experiment plan
- The collimator A to free field ratios compare very well for the threshold reaction in iron and marginally for the thermal reaction in indium
  - Pulse 1 ^{116m}In: measured = 1.03, calculated = 0.82
  - Pulse 1 ^{56}Mn: measured = 0.96, calculated = 1.04
  - Pulse 2 ^{56}Mn: measured = 1.05, calculated = 0.96
- This comparison of the ratios suggest that the differences are due to some global input parameter (number of fissions, material density, etc.) and not the transport algorithm or cross section data

Performance of the CAAS detectors

- Rocky Flats CAAS
  - Pulse 1
    - 3 inside the cell & 1 outside the cell – all alarmed
  - Pulses 2 & 3
    - 2 inside the cell & 1 outside the cell – all alarmed
    - 1 inside the cell (scattering box) did not alarm, which is believed to have been caused by a weak battery that powered the alarm LED
  - Some uncertainty about the number of neutron counts <u>before</u> and <u>hours after</u> the pulses (LLNL will address this later during this technical seminar)
- CIDAS CAAS
  - pulse 1
    - 2 CIDAS in cell and 1 outside the cell were all on the same electrical circuit (single power supply)
    - Only CIDAS in collimator B alarmed (this was the CIDAS CAAS closest to SILENE)
  - pulses 2 & 3
    - 2 CIDAS in cell on a circuit and 1 CIDAS outside the cell on a separate circuit (two power supplies)
    - CIDAS in collimator B & outside the cell alarmed
  - CIDAS circuit arranged such that when one detector on a loop alarms power to the other detectors on that loop is shutoff, but alarm signal is still powered

Future work (FY 2011)

- Read doses absorbed by ORNL TLDs
- Simulate all 3 pulses with a detailed model, and simplify the detailed model to a benchmark model
- Finalize MCNP models
- Collaborate with LLNL to develop a COG benchmark model and CEA Saclay to develop a TRIPOLI-4 benchmark model
- Prepare draft benchmark evaluation of first pulse
- Implement adjoint transport and flux moment tallies into Monaco for SCALE 3D Monte Carlo fixed-source S/U tool
- Prepare draft ORNL report discussing lessons learned during the SILENE CAAS benchmark evaluation and provide user guidance for accurate CAAS analysis